Soil moisture under forest, Bukit Timah Nature Reserve, Singapore

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Abstract

The results of a study of moisture of three forested hill-slope soils are presented and compared with the results of a similar study in Malaya. Soil moisture levels were found in general to be rather higher than under other forms of vegetation. Statistical analysis indicated that change of moisture content was consistent within each soil but less consistent between soils. A series of statistical experiments suggested that except for the A soil horizon, soil moisture (as determined by drying) correlated reasonably well with number of raindays and that the introduction of the factor *e* (evapotranspiration) resulted only in slightly improved correlations except for the A soil horizon where the use of *e* gave much better correlations.

The study of soil moisture in the region is one that is strangely neglected, a search of available literature failing to reveal more than two studies, both concerned with soil moisture as related to rubber. Belgrave (1930, 493–4) made observations from three levels, 2–6 in., 6–12 in. and 12–18 in., of a Serdang series soil having two types of cover, *Centrosema, Mikania,* and under bare soil. Watson, Wong and Narayanan (1963) made eighteen observations at monthly intervals from two levels, 0–6 in. and 12–18 in. of a Rengam series coarse sandy clay loam with a vegetation of two and three year old rubber and cover crops of legumes, grass, adventives and also under bare soil.

Soil Characteristics

The present study reports the results of weekly observations made from mid-February until mid-June 1970 at three points down a surveyed transect line off Jungle Fall path, Bukit Timah Nature Reserve which has a somewhat open lowland Dipterocarp-forest. The upper sampling point, 1, (172 m a.s.l.) was some 25 m from the crest of a gently-rounded interfluve and about 4 m below it with a local slope of almost 15°. The middle sampling point, 2, (141 m a.s.l.) was about 87 m downslope from the first sampling point, 1, and it had a local slope of 24°. Both soils belong to the Rengam series (Leamy & Panton 1966, 105). The lowest sampling point, 3, (126 m a.s.l.) was at the foot of the same slope, 33 m from 2, and located on a small terrace 1.5 m above the level of a small perennial stream. The soil materials were derived from colluvium and alluvium with the former predominating. This soil cannot be assigned to any described series.

The moisture-holding capacity of soil is significantly influenced by grain-size and organic material present. These data are presented for four levels in each soil, 0–10 cm (0–4 in.), 10–20 cm (4–8 in.), 30–45 cm (12–18 in.) and 60–75 cm (24–30 in.), in Table 1. Detailed analysis of grain size was made using the A.S.T.M. standard method (American Society for Testing and Materials, 1963). Only a summary of the data is presented here.

The data for loss on ignition (at 480°C) do not accurately measure total organic matter because the initial oven-dry samples still retain tightly-bound water of hydration. Total organic matter is thus slightly lower than indicated in Table 1.

Table 1. Grain Size (%) according to International System and Loss on Ignition

Sample Point	Depth (cm)	Coarse Sand (2000μ–250μ)	Fine Sand (250μ–25μ)	Silt and Clay (less than 25μ)	Textural name	Loss on Ignition % oven dry wt.
1	0–10	44.6	16.7	38.7	Coarse sandy loam	12.7
	10–20	39.3	12.9	47.8	Coarse sandy loam*	8.8
	30–45	38.2	13.3	48.5	Coarse sandy loam*	7.5
	60–75	34.1	12.2	53.7	Coarse sandy loam	7.0
2	0–10	40.3	21.9	37.8	Coarse sandy loam	10.3
	10–20	37.7	15.3	47.0	Coarse sandy loam†	5.8
	30–45	36.2	18.1	45.7	Coarse sandy loam†	4.5
	60–75	33.5	20.6	45.9	Sandy clay loam	3.7
3	0–10	60.0	5.9	34.1	Not named‡	5.2
	10–20	57.6	20.8	21.6	Coarse sandy loam	5.1
	30–45	56.7	16.1	26.3	Coarse sandy loam	4.4
	60–75	38.5	17.5	44.0	Coarse sandy loam†	7.3

* Almost sandy clay
† Almost sandy clay loam
‡ Suggested name: coarse sandy clay

Collecting Methods

Prior observation established that the maximum variability amongst samples taken from the same level at the same point on the slope was ± one per cent provided that augered samples were taken at points where there were no large roots and which were some distance away from the stems of nearby trees. Successive weekly samplings thus required only one sample from each level at each observation point. Several samples taken at point 3 were notably coarser than the majority and values for moisture are therefore less reliable.

Samples of about 300 gm were augered from each level and immediately placed in polythene bags and sealed. On arrival at the laboratory samples were well-shaken or stirred to incorporate moisture condensing on the inside of the bag and to break down lumps. Samples of about 100 gm were then spooned into dishes for drying at 105°C for 24 hours followed by weighing at 40°C. Prior experiment showed that differences arising from more protracted drying and from cooling in a desiccator to room temperature were much smaller than the differences arising from variations in the exact point sampled. It was however, necessary to weigh dried samples very rapidly taking them one by one from the oven.

Weather

The period of observation began with the dry spell which usually occurs towards the end of the north-east monsoon, and extended through a wetter inter-monsoon period to the early part of the south-west monsoon. Rainfall data were collected daily from a rainfall station some three hundred metres from the soil sampling points. Open pan evaporimeter data were obtained for Paya Lebar Airport some 14 km from Bukit Timah. Soil samples were taken shortly after the daily rainfall measurement was made. Rainfall data are presented at the top of each diagram in Figures 1–3.

Results

The results are presented in Figures 1–3. The diagrams suggest a fairly clear relationship between rainfall and soil moisture, the general trend of low values during dry spells being clear. In the two hill-slope soils points 1 and 2, soil moisture conditions were fairly stable below 30 cm with increasing variability in the upper portions of the soil. This was more marked in the 0–10 cm zone which corresponded with the A_1 soil horizon. Rather large fluctuations, sometimes even during fairly dry periods reflect large but short-lived rises of soil moisture following showers.

The mid-slope soil was slightly drier than the upper-slope soil during the main dry spell but slightly wetter during the remainder of the period. This suggests that greater slope angle and hence more rapid soil drainage becomes influential only during dry spells whereas at other times receipt of upslope water results in slightly moister conditions. Differences of soil texture would seem to be too minor to account for these differences. Furthermore the mid-slope soil contained rather less organic matter than the upper-slope soil and this should have resulted in lower moisture values for the former soil had this been an influential factor.

The slope-foot soil shows an almost complete reversal of the pattern of the other two soils. In it variation was greatest at depth, undoubtedly because of fluctuations in the position of the water-table. The upper zones of this soil were a good deal sandier than those of the hill-slope soils, organic matter was much less and rapid infiltration of rainfall and overland flow from upslope occurred.

The range of moisture is summarised in Table 2.

Discussion

Only the study by Watson, Wong and Narayanan (1963) presents data adequate for some comparisons to be drawn. Expectably the soil moisture values are considerably higher under forest than those under legumes, grass, adventives and bare soil reported in that study. The lowest values at Bukit Timah are roughly equivalent to the mean values at Serdang for the upper 20 cm of soil. The data of Watson *et al* (1964, 165) also show much greater variation of moisture in the 0–15 cm zone than in the 30–45 cm zone. They report moisture values for the 30–45 cm zone which correspond quite well with those of the present study.

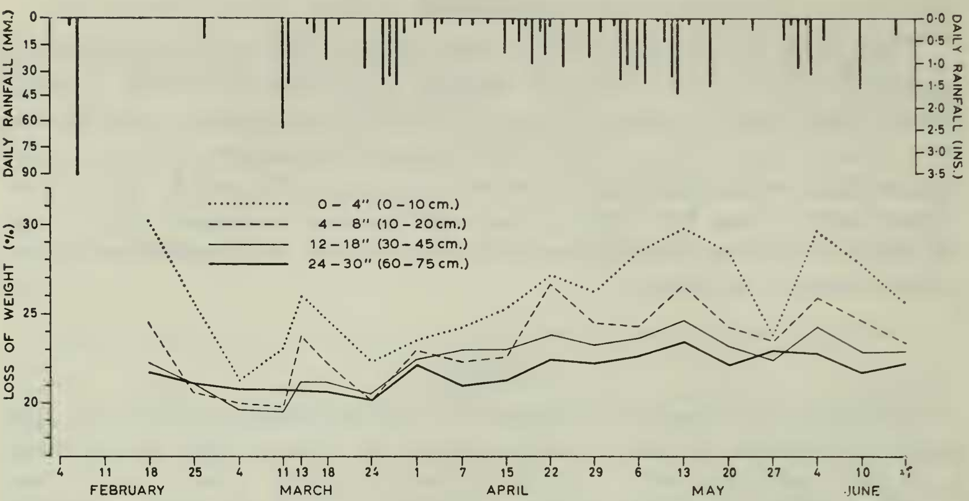

Fig. 1 Soil moisture (loss of weight on drying) for the soil near the top of the slope (1) and daily rainfall.

Table 2. Range of Soil Moisture (%)

Sample Point	Depth (cm)	Highest	Date (1970)	Lowest	Date (1970)	Range
1	0–10	30.2	18-2	21.3	4–3	8.9
	10–20	26.7	22–4	19.9	11–4	6.8
	30–45	24.7	13–5	19.5	11–3	5.2
	60–75	23.5	13–5	20.2	24–3	3.3
2	0–10	31.6	7–4 13–5	20.0	11–3	11.6
	10–20	27.8	10–6	17.9	11–3	9.9
	30–45	23.5	13–5	18.6	4–3	4.9
	60–75	26.4	22–4	20.1	11–3	6.5
3	0–10	23.4	22–4	18.5	4–3	4.9
	10–20	22.9	22–4	20.2	25–2	2.7
	30–45	25.3	22–4	10.1	13–5	6.7
	60–75	30.4	22–4	19.7	1–4	10.7

Statistical Analysis

Two sets of statistical analyses of the hill-slope soils (1 and 2) were made. The first aimed to establish the extent to which the rate of change of soil moisture between successive observations at each level within the soil were correlated. The results are summarised in Table 3 which shows that in general there is a greater degree of association between moisture change at one level within the soil and moisture change at the level below it than between moisture change at the same level of different soils. In other words rates of change within a soil were internally consistent with the notable exception of the soils at 60–75 cm where poor or no correlations with the soils at 30–45 cm were found.

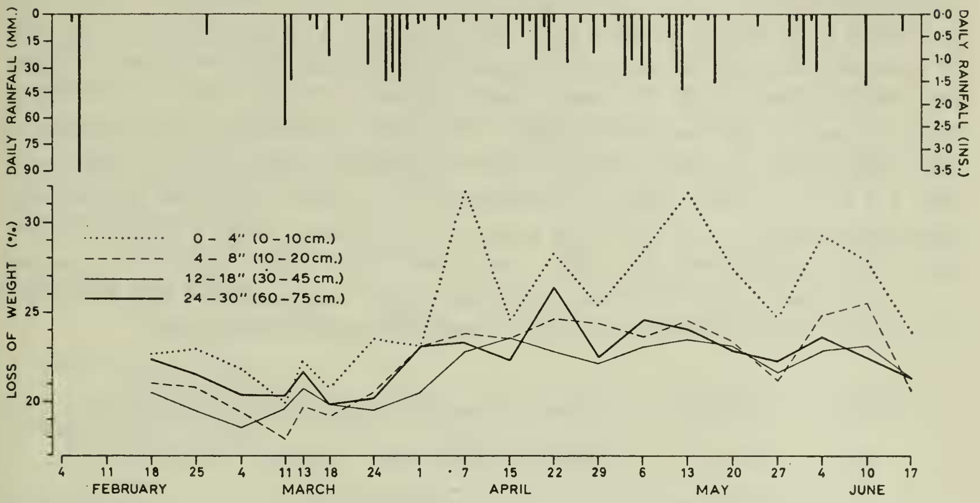

Fig. 2 Soil moisture (loss of weight on drying) for soil on the middle of the slope (2) and daily rainfall.

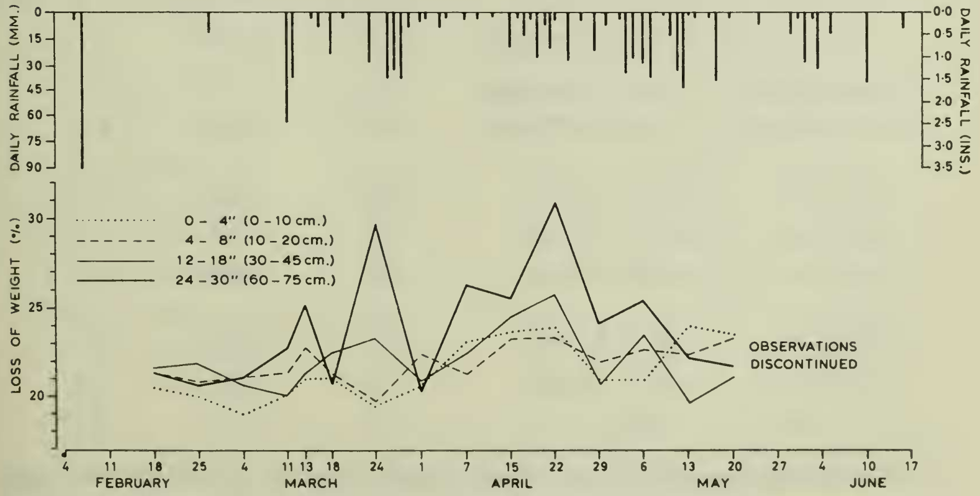

Fig. 3 Soil moisture (loss of weight on drying) for the slope-foot soil (3) and daily rainfall.

The second set of statistical analyses attempted to find a simple parameter with which soil moisture was correlated.

Since soil moisture is affected by a large number of factors including endogenous factors such as grain size and structure and exogenous factors such as rainfall and evapotranspiration, it was hardly to be expected that with only 19 successive observations statistically significant correlations between soil moisture and rainfall alone would be found. Such proved to be the case. Soil moisture was compared with the total rainfall over varying numbers of days prior to each observation. The best, but still poor correlations were first, for moisture in soils 1 & 2, (10–20 cm), with total rainfall over the fourth, third and second days before observation; $r = +0.47$, and second, for moisture in soils, 1 & 2 (60–75 cm), with total rainfall over the fifth, fourth and third days before observation; $r = +0.47$, both values for r being significant at the 5 per cent level with 24 degrees of freedom. Student's t test was used to test significance in each case.

Table 3. Correlations of Rates of Change of Soil Moisture at Various Levels in Soils 1 and 2

Variables		*Degrees of freedom*	*r*	*Significance (better than)*
x	*y*			
1 (0–10 cm)	2 (0–10 cm)	16	+0.76	1%
1 (10–20 cm)	2 (10–20 cm)	18	+0.49	5%
1 (30–45 cm)	2 (30–45 cm)	18	+0.57	1%
1 (60–75 cm)	2 (60–75 cm)	18	+0.56	1%
1 & 2 (0–10 cm)	1 & 2 (10–20 cm)	34	+0.71	0.1%
1 & 2 (10–20 cm)	1 & 2 (30–40 cm)	36	+0.70	0.1%
1 & 2 (30–40 cm)	1 & 2 (60–75 cm)	36	+0.46	1%
1 (0–10 cm)	1 (10–20 cm)	18	+0.71	0.1%
1 (10–20 cm)	1 (30–45 cm)	18	+0.76	0.1%
1 (30–45 cm)	1 (60–75 cm)	18	+0.68	1%
2 (0–10 cm)	2 (10–20 cm)	16	+0.73	1%
2 (10–20 cm)	2 (30–45 cm)	18	+0.60	1%
2 (30–45 cm)	2 (60–75 cm)	18	+0.38	None

A similar comparison of rate of soil moisture change with rainfall was even less satisfactory

A comparison between soil moisture and number of raindays ($>$ 0.1 in. or 2.5 mm per day) in the week preceding measurement gave rather better results and these are shown in Table 4 together with correlations of rate of moisture change with number of rain-days in the preceding week.

Table 4. Correlation of Soil Moisture and Rates of Soil Moisture at Various Levels with Number of Rain-days in Preceding Week

Soil *x*	*y*	*Degrees of freedom*	*r*	*Significance (better than)*
Soil m, 1 & 2, (0–10 cm)	r/days	38	+0.44	1%
Soil m, 1 & 2, (10–20 cm)	r/days	38	+0.56	0.1%
Soil m, 1 & 2, (30–45 cm)	r/days	38	+0.53	0.1%
Soil m, 1 & 2, (60–75 cm)	r/days	38	+0.55	0.1%
Rate of s.m. change, 1 & 2, (0–10 cm)	r/days	34	+0.56	0.1%
Rate of s.m. change, 1 & 2, (10–20 cm)	r/days	36	+0.49	1%
Rate of s.m. change, 1 & 2, (30–45 cm)	r/days	36	+0.47	1%
Rate of s.m. change, 1 & 2, (60–75 cm)	r/days	36	+0.47	1%

In an attempt to gain rather better correlations the factor for evapotranspiration (*e*) was introduced. In this, *e* is evaporation, multiplied by the empirical constant 0.9. The actual formula used was $R - e$, where R = daily rainfall and *e* the daily evapotranspiration. Values of $R - e$ were summed for varying numbers of days prior to each determination of soil moisture. The selected best results are given in Table 5.

Table 5. Selected Correlations of Rates of Change of Soil Moisture with $R - \epsilon$ over Various Days before Moisture Determination

Soil	*Days*	*Degrees of freedom*	*r*	*Significance (better than)*
1 & 2, (0–10 cm)	3, 2, 1	34	+0.57	1%
1 & 2, (0–10 cm)	4, 3, 2	34	+0.60	1%
1 & 2, (0–10 cm)	5, 4, 3	34	+0.45	5%
1 & 2, (10–20 cm)	4, 3, 2	36	+0.44	5%
1 & 2, (10–20 cm)	5, 4, 3	36	+0.31	None
1 & 2, (30–45 cm)	5, 4, 3	36	+0.37	None
1 & 2, (60–75 cm)	5, 4, 3	36	+0.42	5%

It will be seen from Table 5 that the introduction of the factor *e* which might have been expected to have added precision to the correlations failed to do so except in the case of the uppermost layer of soil from 0–10 cm.

In order that higher values for *r* might be obtained the empirical formula $Rw - e$ was used. It was felt desirable to retain the factor *e* since it represents a continuous process which results in loss of soil moisture. It was also desirable to weight the value *R* since rain falling seven days before a soil moisture determination would have much less effect upon the soil moisture level than rain falling in the day before the measurement. Rainfall was weighted with the following values, corresponding to 1, 2, 3 . . . 7 days before measurement; 1.0, 0.93, 0.85, 0.74, 0.60, 0.40, 0.10 which approximate to an exponential curve. The values for *R weighted — e* were then summed for varying periods prior to each moisture determination and separately correlated with soil moisture and rate of change of soil moisture. Selected results, giving highest values for *r*, are given in Tables 6 and 7.

Table 6. Selected Correlations of Soil Moisture with *R weighted — e*, over Various Days before Moisture Determination

Soil	*Days*	*Degrees of freedom*	*r*	*Significance (better than)*
1, (0–10 cm)	5 . . . 1	19	+0.46	5%
1, (10–20 cm)	5 . . . 1	19	+0.67	1%
1, (30–45 cm)	7 . . . 2	19	+0.66	1%
1, (60–75 cm)	7 . . . 2	19	+0.60	1%
2, (0–10 cm)	5 . . . 1	19	+0.67	1%
2, (10–20 cm)	5 . . . 1	19	+0.57	1%
2, (30–45 cm)	7 . . . 2	19	+0.57	1%
2, (60–75 cm)	7 . . . 2	19	+0.62	1%
1 & 2, (0–10 cm)	5 . . . 1	37	+0.56	1%
1 & 2, (10–20 cm)	5 . . . 1	38	+0.59	1%
1 & 2, (30–45 cm)	7 . . . 2	38	+0.59	1%
1 & 2, (60–75 cm)	7 . . . 2	38	+0.57	1%

Table 7. Selected Correlations of Rate of Soil Moisture Change with *R weighted — e* over Various Days before Moisture Determination

Soil	*Days*	*Degrees of freedom*	*r*	*Significance (better than)*
1, (0–10 cm)	5 . . . 1	18	+0.65	1%
1, (10–20 cm)	5 . . . 1	18	+0.61	1%
1, (30–45 cm)	7 . . . 2	18	+0.63	1%
1, (60–75 cm)	7 . . . 2	18	+0.40	None
2, (0–10 cm)	5 . . . 1	18	+0.67	1%
2, (10–20 cm)	5 . . . 1	19	+0.57	1%
2, (30–45 cm)	7 . . . 2	19	+0.57	1%
2, (60–75 cm)	7 . . . 2	19	+0.62	1%
1 & 2, (0–10 cm)	5 . . . 1	37	+0.56	1%
1 & 2, (10–20 cm)	5 . . . 1	38	+0.59	0.1%
1 & 2, (30–45 cm)	7 . . . 2	38	+0.59	0.1%
1 & 2, (60–75 cm)	7 . . . 2	38	+0.57	0.1%

These data suggest that while correlation with this empirical formula gives slightly higher values for r than correlations with number of rain days, especially for the upper layer of the soil, the introduction of the factor e is hardly necessary. The weighting of R would also seem to be barely worth the labour of computation involved. The conclusion is therefore, that with the exception of the upper layer of the soil where the introduction of e is desirable, the number of rain days in the period (here a week) before the measurement of soil moisture provides a simple parameter from amongst the meteorological factors affecting soil moisture. Since the method of determining soil moisture is by no means highly accurate, the coupling with it of such a 'rough-and-ready' measure as raindays seems justifiable, whereas the use of more sophisticated meteorological parameters is scarcely worth the labour involved.

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